First Results from ACPC Case Studies on Aerosol Effects on Shallow and Deep Clouds

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The Aerosols-Clouds-Precipitation-and-Climate (ACPC) Initiative aims at a better understanding and quantification of the impact of aerosol perturbations on clouds, radiation, precipitation, latent heating and atmospheric circulation. Following roadmaps defined and iterated at earlier meetings (see: *http://research.uni-leipzig.de/acpc/meeting2017.html* and summarized in workshop reports, Quaas et al., 2015; 2016), and a comprehensive review paper summarizing earlier work within ACPC (Rosenfeld et al., 2014), the initiative focuses on two cloud regimes—shallow marine clouds and deep convective clouds. Ongoing work and recent results were discussed at a workshop held at the Physikzentrum Bad Honnef in Germany from 2–6 April 2017.

Research on deep convective clouds is currently focused on isolated convective cells over Houston, Texas, USA. This research is guided by the substantial perturbation in cloud condensation nuclei (CCN) concentrations caused by pollution from Houston in onshore flow that is in contrast to much less polluted conditions in the vicinity as observed by new satellite products (Rosenfeld et al., 2016). The aerosol perturbation under onshore flow conditions offers the possibility of observing the evolution of convective cells under relatively uniform thermodynamic conditions.

On the observations side, emphasis is placed on the analysis of radar measurements. Groups at the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS), Texas A&M University, the National Atmospheric and Oceanic Administration and the National Severe Storms Laboratory identified convective cells in polarimetric radar data from the Next-Generation Weather Radar (NEXRAD) network and tracked them over their lifetime. Preliminary analysis of the NEXRAD data and collocated Lightning Mapping Array observations indicate that characteristics of isolated cell evolution differ between situations subject to relatively high versus low CCN conditions. One study by the Texas A&M University and the Hebrew University of Jerusalem proposed from a statistical analysis of observations that these clouds had greater vertical development, larger hydrometeors and enhanced lightning, hypothesizing that this might be due to invigoration (Andreae et al., 2004; Rosenfeld et al., 2008). Through interaction with experts on radar observations, the group proposes new radar observation strategies that may allow for improved tracking of rapidly evolving cell development, in particular using mobile polarimetric radars that can offer rapid scan capabilities. A group at Stony Brook University and NASA GISS used forward simulation from preliminary simulations to demonstrate potential minimum requirements (distances from target, number of radars) for radars to adequately observe isolated cells and potentially retrieve vertical wind speed.

On the modeling side, a common case study protocol for simulations of deep convective clouds has been defined (details are available at: *www.acpcinitiative.org*) and first simulations were conducted with two cloud-resolving models. These simulations from Colorado State University and the University of Oxford showed distinct differences between the high- and low-CCN simulations in vertical wind and specific ice content, albeit with little signal in surface precipitation. This latter finding was also evident in an ensemble of simulations conducted by the University of Leeds for a different convective case, where it was very clear that even very large aerosol perturbations do not produce signals in precipitation distinguishable from the uncertainty range as represented by the ensemble spread. However, other properties differed notably but not entirely consistently across the models tested; such differences between models are expected based on substantial uncertainties in microphysics schemes (White et al., 2016), in part motivating a strong parallel effort on the observation side. Based on a new analysis of data from the air quality focused field study, Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ), by the Max Planck Institute for Chemistry, the prescribed CCN profiles of the case study protocol will be revised. A next step is to invite the wider modeling community to contribute more simulations and to forward-simulate polarimetric radar signals from the simulations for comparison to the hypotheses on aerosol signals proposed on the basis of the observations analysis.

Based on these results, ACPC is working towards a first field campaign where at least one mobile radar from potential U.S. sources can be deployed and the methods for rapid scanning and statistical assessment of the observations can be tested on site in the Houston area. The model simulations in the deep convective cloud case study will help to develop and test observational strategies for the field campaign; examples include testing the potential capability to measure wind convergence profiles using high-resolution dropsonde arrays over 100-km-diameter columns (based on preliminary results by the Laboratoire de Météorologie Dyanmique and Max Planck Institute for Meteorology) and assessing the observational strategy to achieve a box closure experiment (Rosenfeld et al., 2014).

With regard to shallow clouds, research has focused on the southeastern Pacific stratocumulus region, where the Variability of the American Monsoon System (VAMOS) Ocean-Cloud-Atmosphere-Land Study (VOCALS) field campaign made comprehensive measurements in October–November 2008. Statistical relationships between aerosol optical depth and cloud droplet number concentration, N_d, and between N_d and cloud liquid water path (LWP, Michibata et al., 2016) are being assessed from available simulations and satellite retrievals and put into the context of anthropogenic perturbation (cf. Gryspeerdt et al., 2017).

First results from the University of Leipzig show similarities to the satellite-derived relationships in some models, but not in all (see figure on page 1). From a set of simulations by the University of Leeds, new results suggest the possibility of identifying clear signals of anthropogenic effects on clouds even in top-of-atmosphere radiation (Grosvenor et al., 2017). A new effort is now directed at running large eddy simulations (LES) along Lagrangian trajectories derived from a coarse grid Weather Research and Forecasting (WRF) model. This amounts to a downscaling exercise in which a LES provides a more detailed view of aerosol and cloud processes along the stratocumulus to cumulus transition. Trajectories were initiated near the Chilean coast in closed cell stratocumulus decks under polluted conditions and followed towards the open ocean where the regime changed to broken cumulus cloudiness, with a corresponding reduction in aerosol loading. Sensitivity to WRF forcing has been explored but much more work needs to be done.

The Shallow Cloud Working Group, along with continuing research along these lines, will broaden the focus to also consider stratocumulus and their transition to cumulus in the Southeast Atlantic under the influence of biomass burning smoke [the Observations of Aerosols above Clouds and their interactions (ORACLES)/CLoud-Aerosol-Radiation Interactions and Forcing (CLARIFY)/Layered Atlantic Smoke Interactions with Clouds (LASIC) campaigns]; also trade-wind cumulus clouds will be observed along with a comprehensive characterization of the large-scale weather conditions in the Elucidating the Role of Cloud-Circulation Coupling in Climate (EUREC4A) campaign (*http://eurec4a.eu/*). Finally, because the Shallow Cloud Group to a large extent assesses satellite data, one ongoing effort within ACPC is to characterize capabilities and uncertainties of current cloud droplet number concentration calculations based on satellite-based cloud optical depth and drop effective radius retrievals, and to assess new and upcoming approaches.

A follow-up workshop is planned for 4–6 April 2018 in Colorado, USA. The ACPC group welcomes interested persons or groups to join the activities.

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